COLD CATHODES FOR APPLICATIONS IN POOR VACUUM AND LOW-PRESSURE GAS ENVIRONMENTS: CARBON NANOTUBES VERSUS ZINC OXIDE NANONEEDLES

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Carbon nanotubes and ZnO nano-needles were grown on silicon substrates and used as cold cathodes. These cold cathodes exhibit excellent electron field emission characteristics in high vacuum with turn-on electric field near 1 V/μm and below. Long-term stability of electron field emission for cold cathodes coated with carbon nanotubes and ZnO are compared. The effects of gas pressure on the characteristics of electron field emission are reported and discussed. Electron field emission current for both cold cathodes coated with carbon nanotubes and ZnO decreases with air pressure that is intentionally leaked into the experimental chamber. For the same air pressures up to tens of mTorr, ZnO nano-needle coated cold cathodes exhibit percentage-wise less decrease in electron field emission current as compared to carbon nanotube coated cold cathodes. ZnO nano-needles appear to be more favorable for cold-cathode applications in poor vacuum environments and for low-pressure gas-filled electron devices.

The extremely high aspect ratios and/or small radius of curvature of nanoscale materials such as nanotubes, nanowires, nanoneedles, nanoparticles, and nanocrystalline grains have been explored and reported to promote the field emission of electrons at low applied electric fields in vacuum. Among these nano-scale materials, carbon nanotube is the most well studied material for cold cathode applications because of both its high aspect ratio and the small radius of curvature at its tip. Numerous publications have reported the effects of diameter, length, spacing between carbon nanotubes, tip geometry and composition, placing and patterning, and post-deposition processing on the electron field emission characteristics of carbon nanotubes. Effects of residual gases that are adsorbed on the surfaces of carbon nanotubes have also been studied.

For some practical applications, the electron field emission must operate in a poor vacuum or at a low gas pressure with an intentionally filled gas. Energetic oxygen molecules, atoms and ions are known to react with carbon nanotubes causing defect formation and etching of the exposed carbon nanotubes resulting in the degradation of the electron field emission characteristics.

Oxide nanowires or nano-needles are expected to be more resistance to environments containing oxidizing species. In this paper, ZnO is chosen as the oxide cold cathode material for a comparison with non-oxide carbon based cold cathodes that are coated with carbon nanotubes.

Both carbon nanotubes and ZnO nano-needles are deposited on silicon substrates by means of thermal chemical vapor deposition methods. ZnO nano-needles are grown on silicon using gold nanoparticles as a catalyst in the presence of Zn vapor. Carbon nanotubes were grown by means of thermal chemical vapor deposition using iron as a catalyst in the gas mixture of acetylene and argon.

Electron field emission measurement is done in a vacuum chamber with base pressure of 10^{-6} Torr. An air leak valve can be turned on to allow controlled amount of ambient air to enter the chamber for a desired air pressure. Cold cathode is place at a distance from the anode of 3 mm^2 in surface area by means of spacers. The anode is inserted in an electrical insulating block. Spacers are placed between the cathode and the electrically insulating block so that in case the side walls of the spacers are coated with conducting materials, the measurement of electron field emission current will not be affected.

A TEM photograph of carbon nanotubes and a SEM photograph of ZnO nanoneedles are shown in Figure 1 (i) and (ii), respectively. Electron field emission current as a function of the applied electric fields using the air pressure as a parameter is measured using a tungsten anode of 3 mm^2 in area. Both cold cathodes allow electron field emission to be detected at an applied electric field around 1 V/μm or below (not shown in this figure of linear scale). The electron field emission current measured from the carbon nanotube coated cathode is higher than that measured from the ZnO nanoneedle coated cathode because the number density and concentration of electron emission sites of ZnO nanoneedles used for this experiment are not as high as that of carbon nanotubes. Figure 2 shows that as the air pressure increases, the electron field emission currents for both cathodes decrease with the carbon nanotube coated cathode showing more dramatic decrease than the ZnO nanoneedle coated cathode. Electron field emission current measurement is repeated in vacuum after exposing both cold cathodes to electron field emission at a gas pressure of 60 mTorr. ZnO nanoneedles recover most of the original electron field emission characteristics; but, carbon nanotubes exhibit electron field emission current several orders of magnitude less than the original field emission current before being subjected to electron field emission at 60 mTorr as shown in Figure 2.

In summary, both carbon nanotubes and ZnO nanoneedles serve as excellent electron field emission cold cathode coatings with low turn-on electric fields in high vaccum. The electron field emission current decreases with increasing air pressure. ZnO nanoneedles is more favorable for cold cathode applications in poor vacuum and in low pressure environments filled with oxidizing gases.

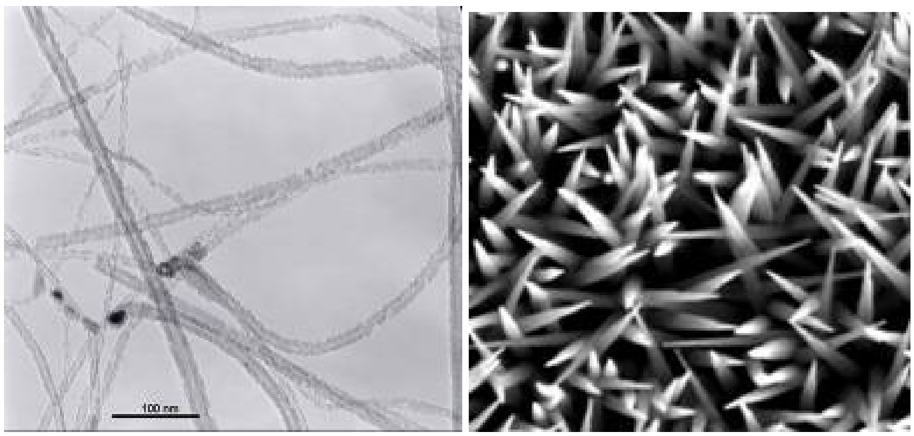

Figure 1. (i) TEM photograph of carbon nanotubes. (ii) SEM photograph (9x9 μ) of ZnO nano-needles.

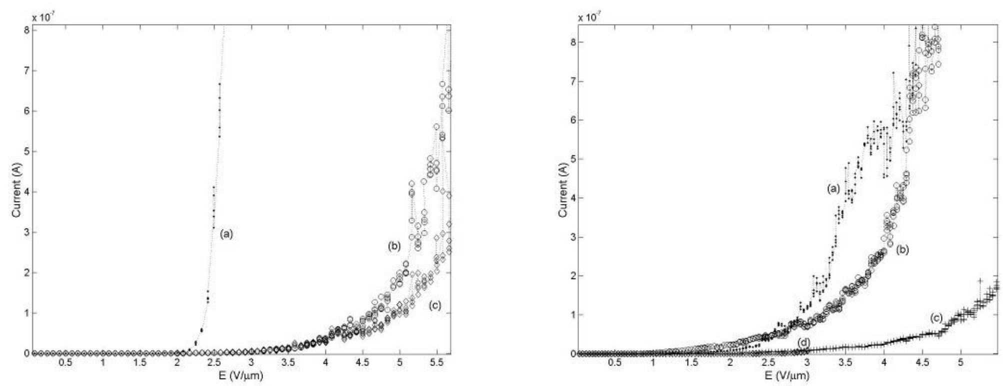

Figure 2. (i) I-E curves for carbon nanotubes. (ii) I-E curves for ZnO nano-needles.

For both sets of curves the electron field emission current was measured for (a) the as-grown samples at 10^{-6}Torr and (b) the same samples at the same pressure of 10^{-6}Torr after being subjected to the environments in which electron field emission in ambient air at a pressure of 60 mTorr was measured . Curve (i-c) and (ii-d) are for measurements at 60 mTorr. Curve (ii-c) is for measurement at 30 mTorr.